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Application of IASOA circumpolar observations in studies of atmospheric transports into and out of the central Arctic

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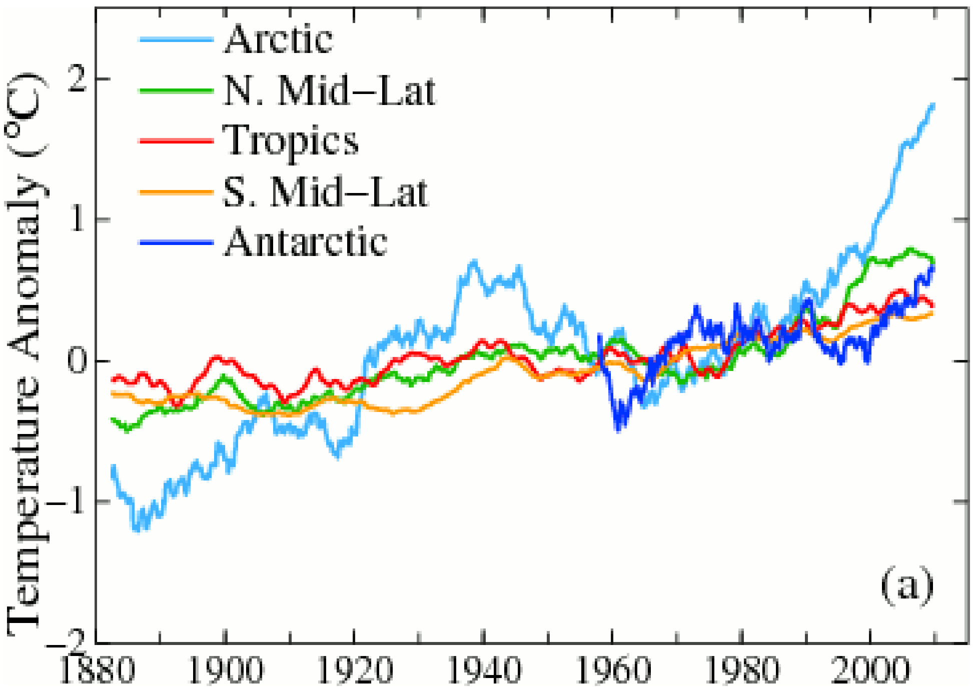
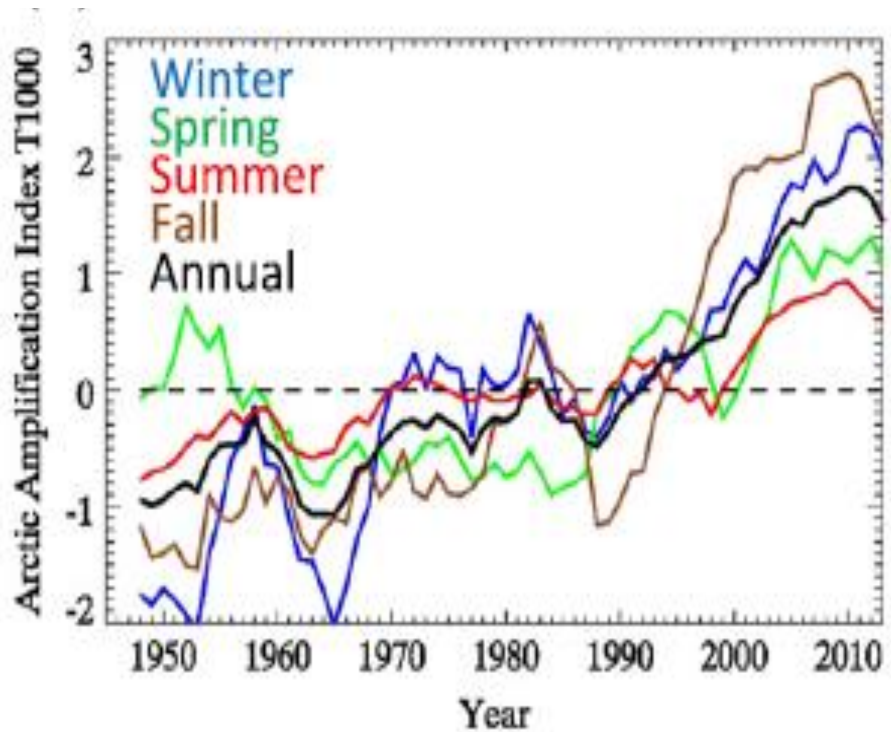
1. INTRODUCTION AND MOTIVATION

Arctic amplification of climate warming

Zonal mean temperature changes



Sato and Hansen (2016)

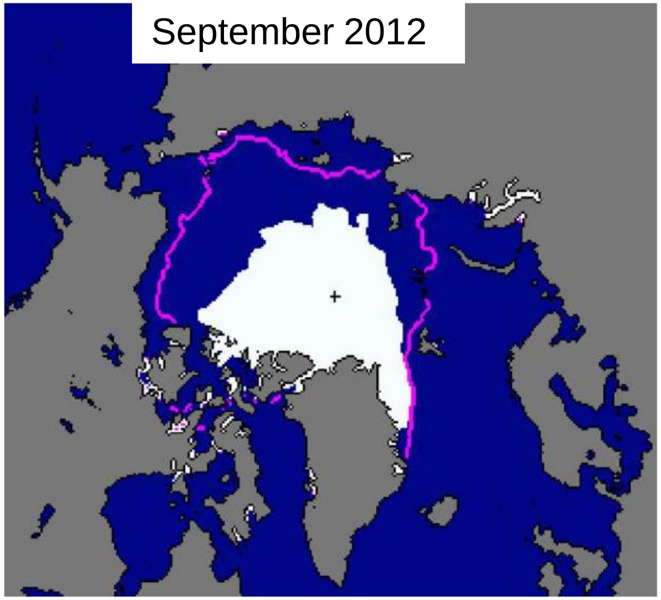


Arctic amplification seasonal time series (relative to 1948–2013 mean, °C) between the Arctic (70–90°N) and mid-latitudes (30–60°N). Francis and Vavrus (2015).

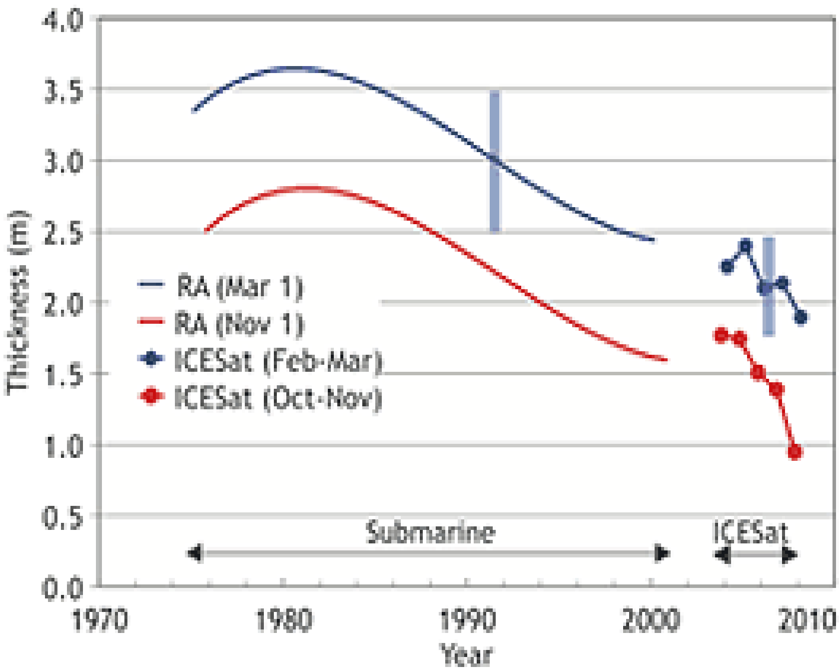
Sea ice decline

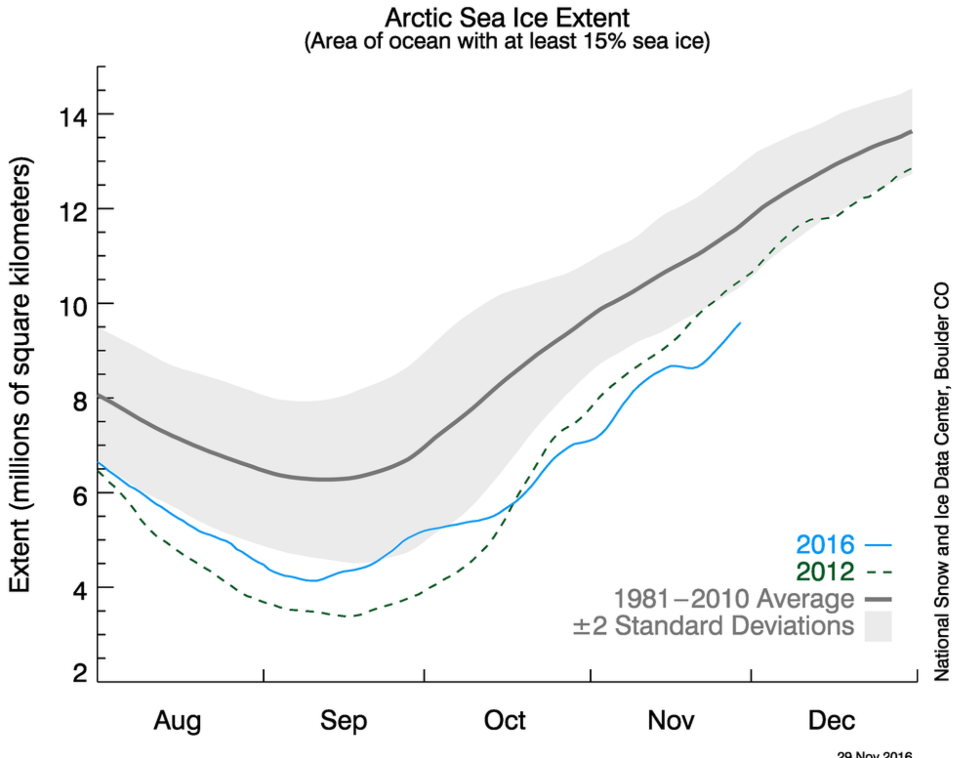
- Thickness reduced by roughly 50% since 1980

- In late summer and autumn, extent reduced by roughly 40% since 1980



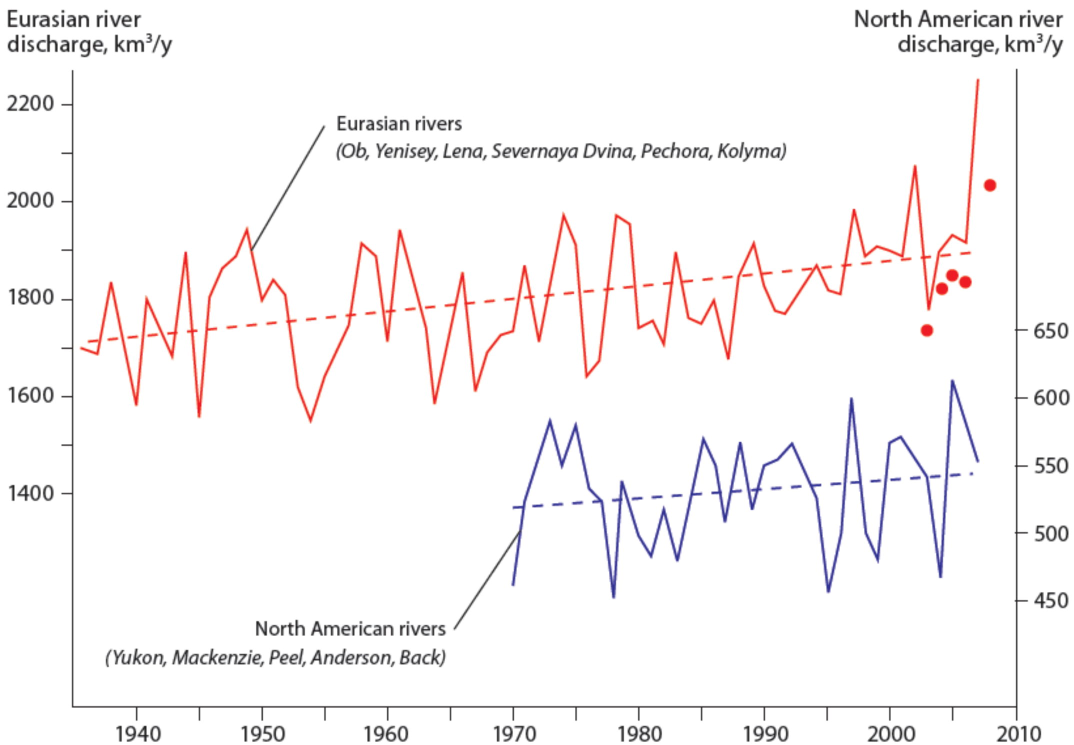
Kwok and Rothrock (2009)



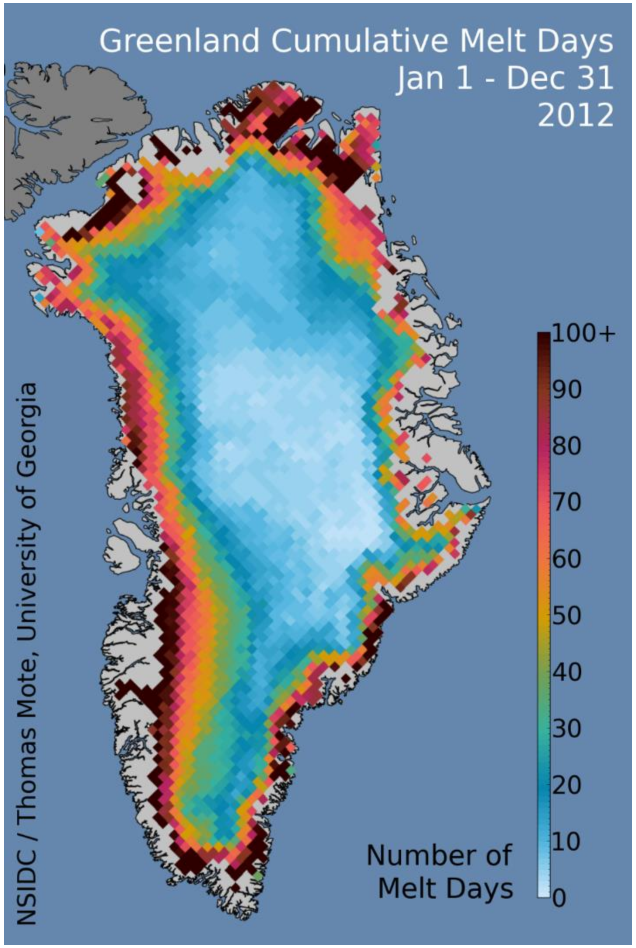


Changes in terrestrial Arctic and boreal regions

- June snow cover loss twice fast as the loss of summer sea ice
- Increases in precipitation, net precipitation and river discharge
- Accelerated melt of Greenland ice sheet and smaller glariers



Discharge from largest rivers to the Arctic Ocean
(Richter-Menge and Overland, 2009)



Contribution of mid- and lower latitudes to Arctic warming

- Vecchi and Bond (2004): Madden-Julian Oscillation (MJO) can influence high-latitude surface temperatures.

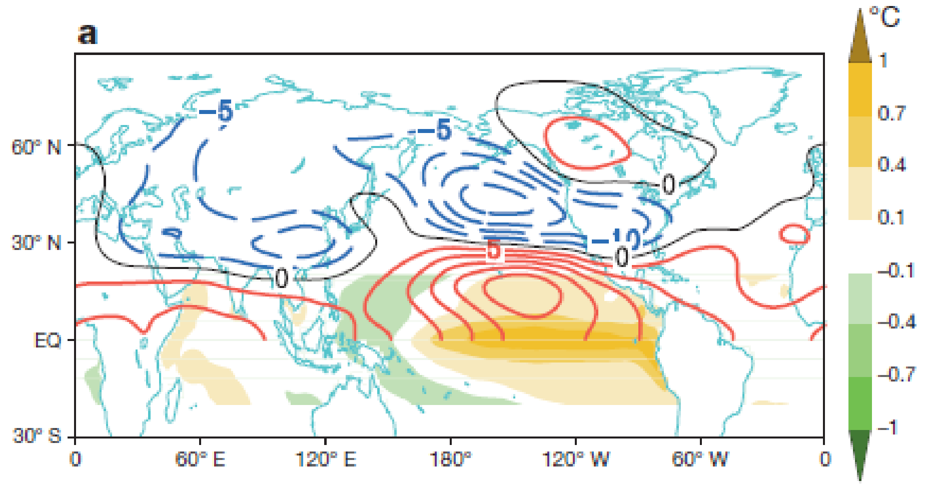
- Lee et al. (2011): convection over the tropical Indian and western Pacific Oceans plays a major role in the Arctic amplification via exciting hemispheric-scale circulation patterns

- Screen et al. (2012) and Perlwitz et al. (2015): SST changes at lower latitudes explain the majority of observed Arctic warming in lower- and mid-troposphere.

- Sato et al. (2014): a major factor for warming in the Barents and Kara seas has originated from the Gulf Stream region, where a SST front has shifted poleward.

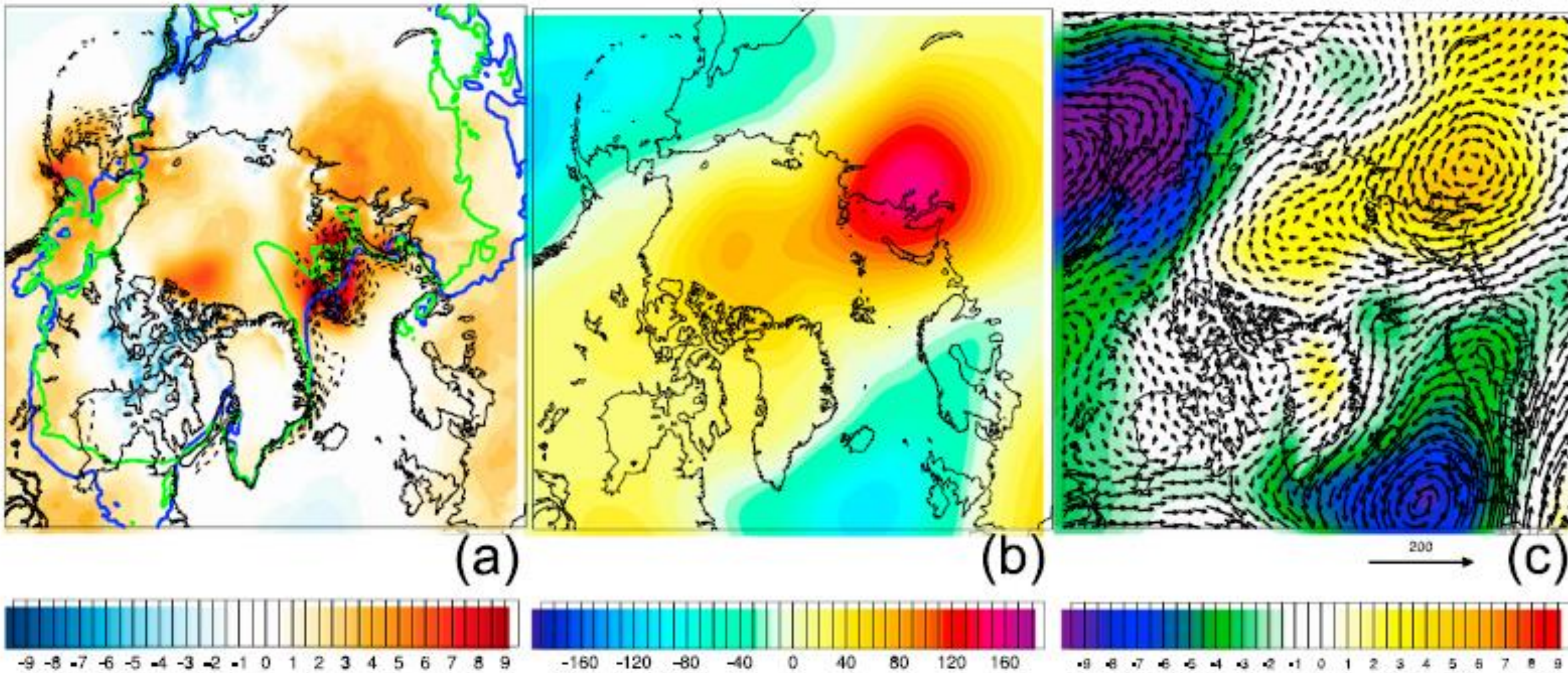
- For the same pattern and amount of sea-ice loss, consequent Arctic warming is larger during the negative PDO phase relative to the positive phase (Screen and Francis, 2016)

- Ding et al. (2014): recent warming in north- eastern Canada and Greenland related to anomalous Rossby wave-train activity originating from a specific SST pattern in the tropical Pacific



Recent Extremes in the Arctic

Winter 2015-2016



Teleconnections from the Atlantic -> warming over Eurasian high-latitude land surfaces

El Niño -> warming over southwestern Alaska and British Columbia

Clouds and increased downwelling longwave radiation -> warm anomalies over the central Arctic.

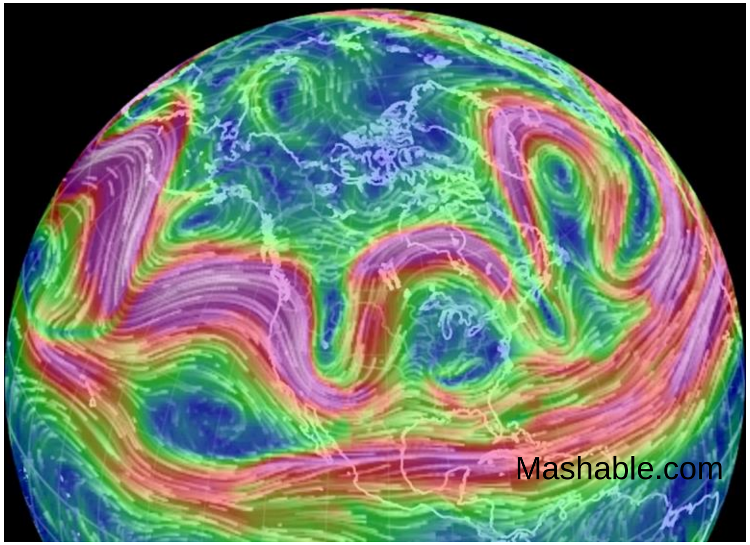
Warm winter -> spring sea ice decline

Cullather et al. (2016)

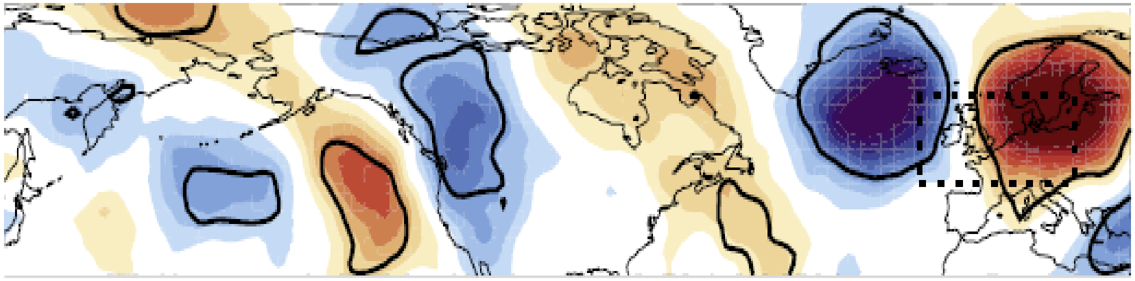
Arctic efffects on mid-latitudes

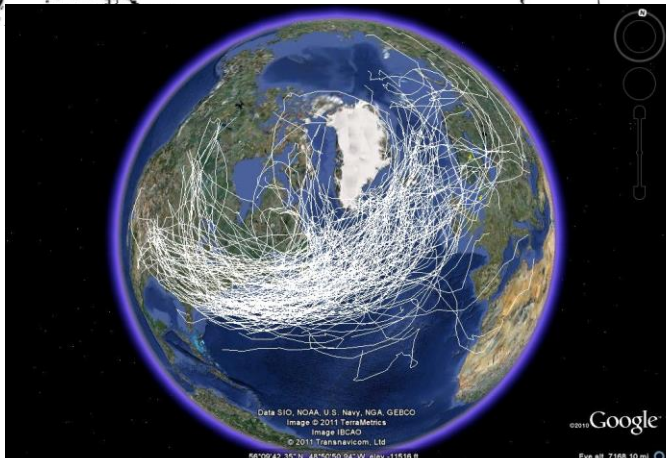
Over the land area from 20° to 50°N, occurrence of warm extremes has increased since 1970s, and occurrence of cold extremes since about 2000 (Cohen et al., 2014). Due to Arctic changes?

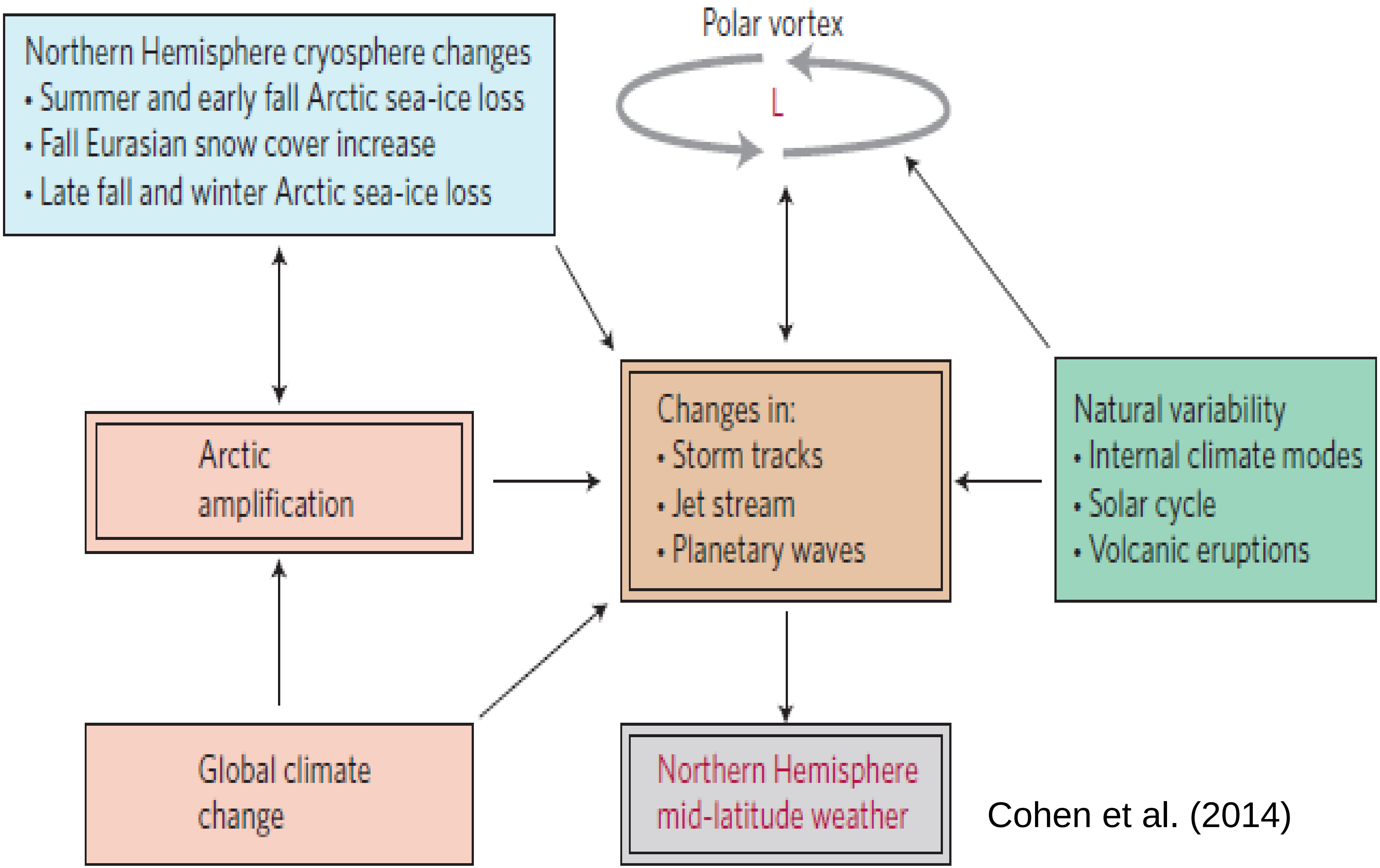
Important features of large-scale atmospheric dynamics: Polar front jet stream, planetary waves, high-pressure blockings, transient cyclones



Screen (2013)







Cohen et al. (2014)

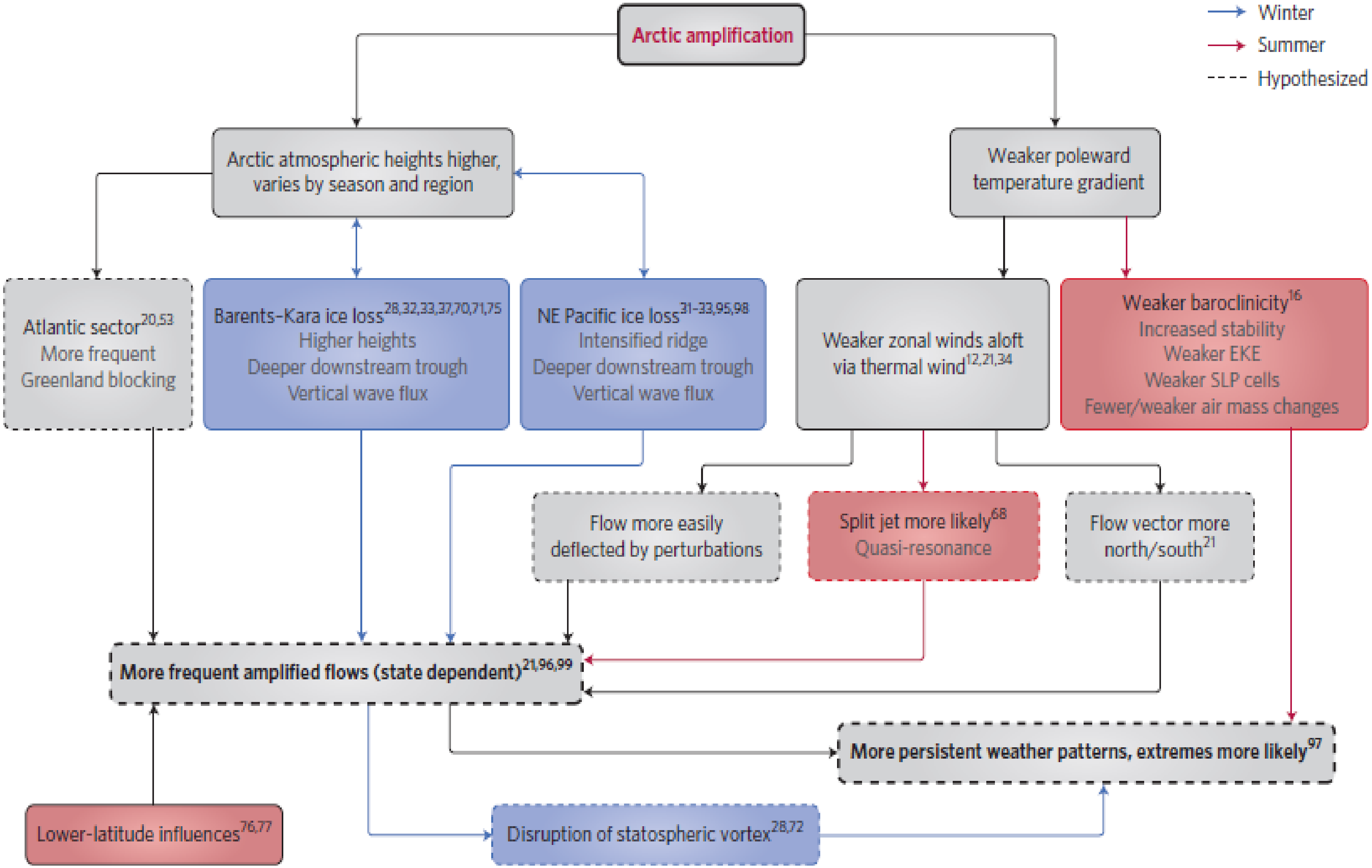


Figure 2 | A complex web of pathways summarizing examples of potential mechanisms that contribute to more frequent amplified flow and more persistent weather patterns in mid-latitudes. EKE, eddy kinetic energy; SLP, sea-level atmospheric pressure. For details on the processes, consult the original references.

Overland et al. (2016), Nature Climate Change

All the above calls for better quantitative understanding on the atmospheric transports of heat, momentum, potential energy, moisture, other greenhouse gases, clouds, and aerosols from lower latitudes to the Arctic and vice versa.

- circumpolar estimates only possible based on gridded products
- include errors and uncertainties
- evaluation possible on the basis of data fromn surface weather stations, radiosonde soundings, and IASOA observaties
- seasonal and longitudinal variations of the transports
- vertical structure of the transports
- impacts of the transports

IASOA observatories

Table 1. Summary of IASOA stations with focus on observations needed for estimation of atmospheric transports.

Station	Altitude (asl), surroundings	Atmospheric vertical profiles
Barrow	8 - 20 m, tundra, coastal	Radiosonde soundings (RS), wind and aerosol lidars, wind radars, spectral radiometers for temperature and humidity profiles
Oliktok Point	5 m, tundra, coastal	Unmanned Aerial Vehicles (UAV) and tethersonde soundings for wind, temperature, and humidity profiles during campaigns
Eureka	0 – 620 m, tundra, archipelago	RS, wind and aerosol lidars, wind radar, spectral radiometers for temperature, humidity, and cloud condensate profiles
Alert	8 - 210 m, tundra, coastal	RS
Summit	3250 m, flat ice sheet	RS, wind and aerosol lidars, wind radar, spectral radiometers for temperature, humidity, and cloud condensate profiles
Villum Research Station	24 m, tundra, coastal	RS during campaigns
Ny Ålesund	0 – 30 m (473 m for Zeppelin mountain), tundra, complex orography of a fjord	RS, wind lidar, spectral radiometers for temperature, humidity, and cloud condensate profiles, tethersonde for wind, temperature, and humidity profiles during campaigns
Sodankylä – Pallas	Sodankylä: 179 m, boreal forest, swamps, river; Pallas: 565 m, fjell, tundra	RS (Sodankylä) Lidar for wind and aerosols (Pallas)
Tiksi	1-30 m, tundra, coastal	RS, spectral radiometers for temperature, humidity, and cloud condensate profiles
Cherskii	16 m, taiga forest, inland	RS
Cape Baranova	24 m, glacier, tundra, coastal	RS, lidar, occasionally UAV

Need to develop usable products and analysis tools

- to compare point observations against grid-averaged model or satellite products
- to compare obs. and model/satellite products with different temporal resolution
- to compare different variables observed and modelled
- to standardize observation products across the network of ten stations

Tools already available:

- extraction of reanalysis output: NCEP/NCAR, NCEP/DOE AMIP-II, NARR
- NSIDC tool to subset certain MODIS data for IASOA sites

Usage and added value of IASOA observations

Ground truth for remote sensing observations

- snow/ice surface is a problem particularly for remote sensing of atmospheric moisture, cloud water, and cloud ice
- surface-based observations essential for assessing the validity of many satellite products. In turn, satellite products provide a spatial context for in situ point observations
- High-quality satellite observations are important also for reanalyses and operationan analyses of NWP models

Observatory design considerations for the use of surface-based observations for satellite product validation:

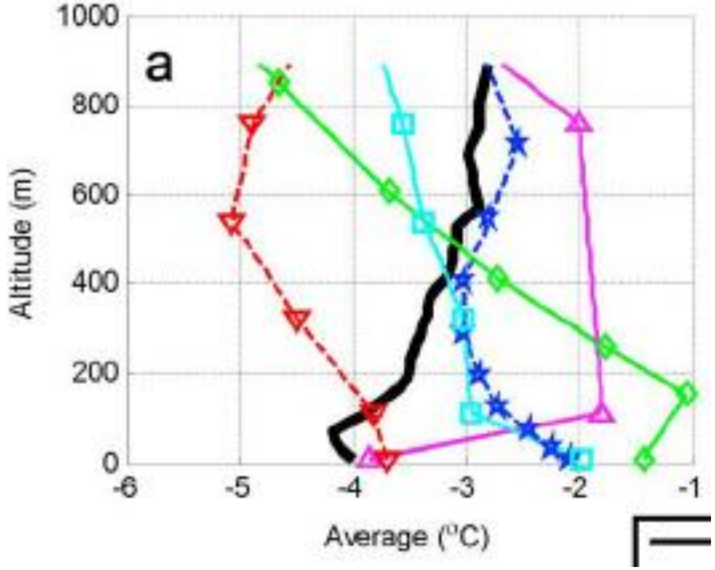
- everything that affects the radiation between the satellite and the feature of interest (e.g., clouds) would ideally be measured from the surface and fully characterized
- Surface-based measurements should be representative of a satellite field-of-view
- Prioritization: parameters that are most difficult to estimate from space provide one perspective on user needs. Among others, the strength and depth of low-level temperature and humidity inversions, cloud optical depth, and the frequency of occurrence of mixed-phase clouds
- IASOA super-sites (Barrow, Eureka, Summit) are an extremely valuable and under-utilized resource for satellite validation

Usage and added value of IASOA observations

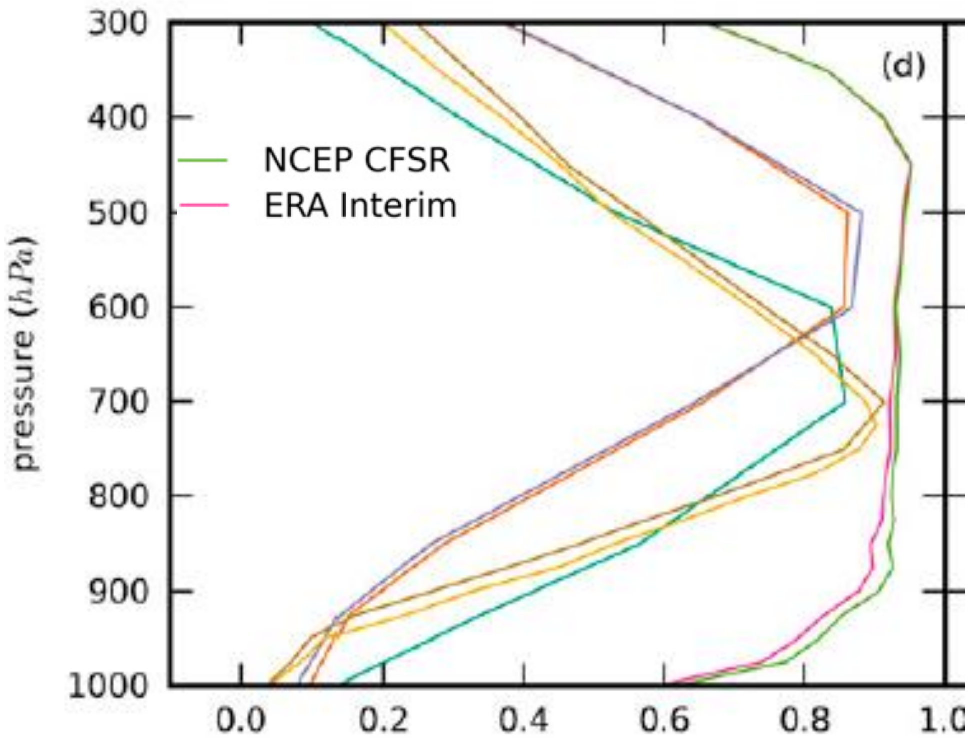
Evaluation of atmospheric models and research on regional transports

- So far mostly done on the basis of other data sets

Challenges in models and reanalyses



Jakobson et al. (2012): observed Ta ovser central Arctic compared against 5 reanalyses



Dufor et al. (2016): Meridional moisture flux anomaly correlation between radiosonde soundings and eigth reanalyses

Added value of IASOA data compared to radiosonde sounding data (36 stations north of 65N): profiles of cloud water and ice content and aerosols

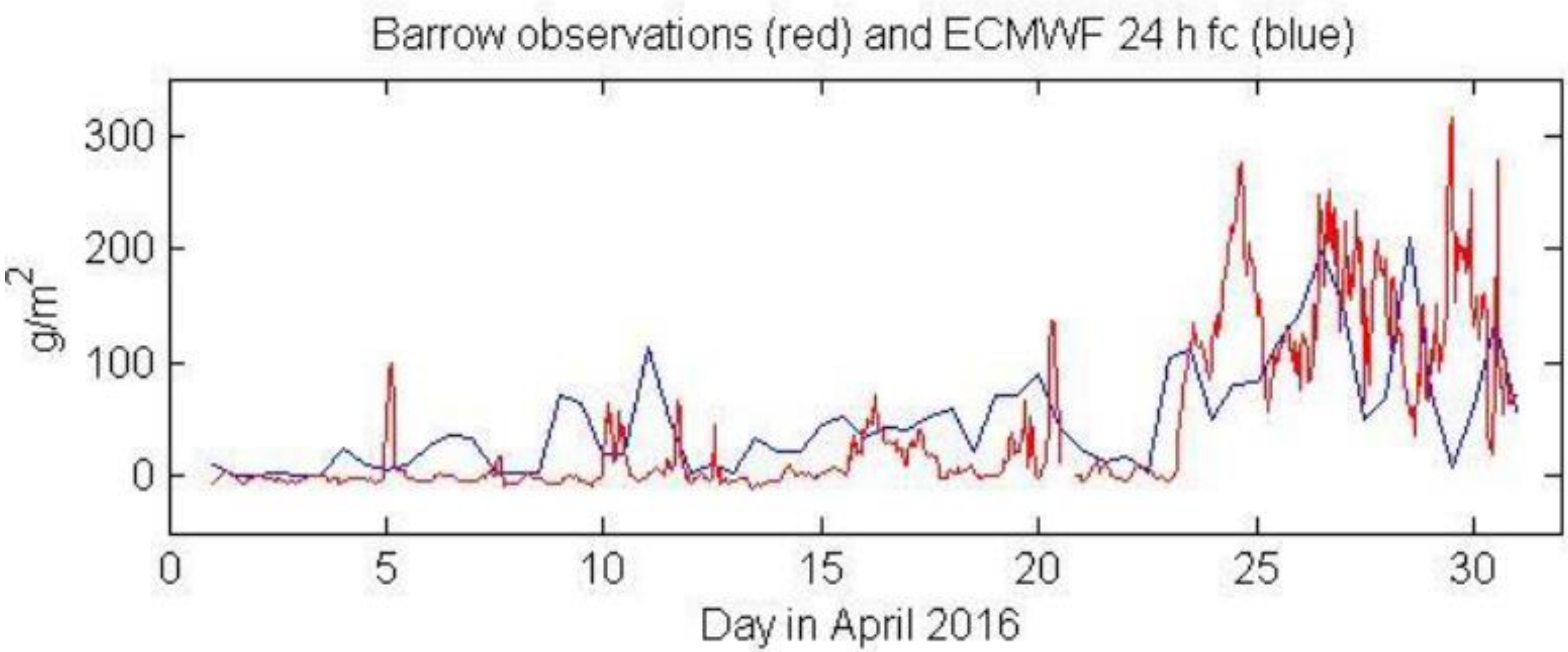


Figure 3. Comparison of IASOA observations and ECMWF 24 h forecasts for of cloud water path at Barrow in April 2016. The observations are from Atmospheric Radiation Measurement (ARM) Climate Research Facility (1996), processed applying an algorithm by Turner et al. (2007).

-> estimates of the biases and uncertainties of circumpolar transports calculated on the basis of the gridded products.

-> selection of methods to obtain most accurate transports

Evaluation of reanalyses, weather and climate models, and satellite remote sensing products with respect to surface variables:

- snow depth, soil moisture, surface temperature, shortwave and longwave radiative fluxes, albedo, turbulent fluxes of sensible heat, latent heat, carbon dioxide and methane.

To estimate budgets, evaluation of surface fluxes is vital, complementing the evaluation of horizontal transports.

Comparison of related variables, to better understand processes

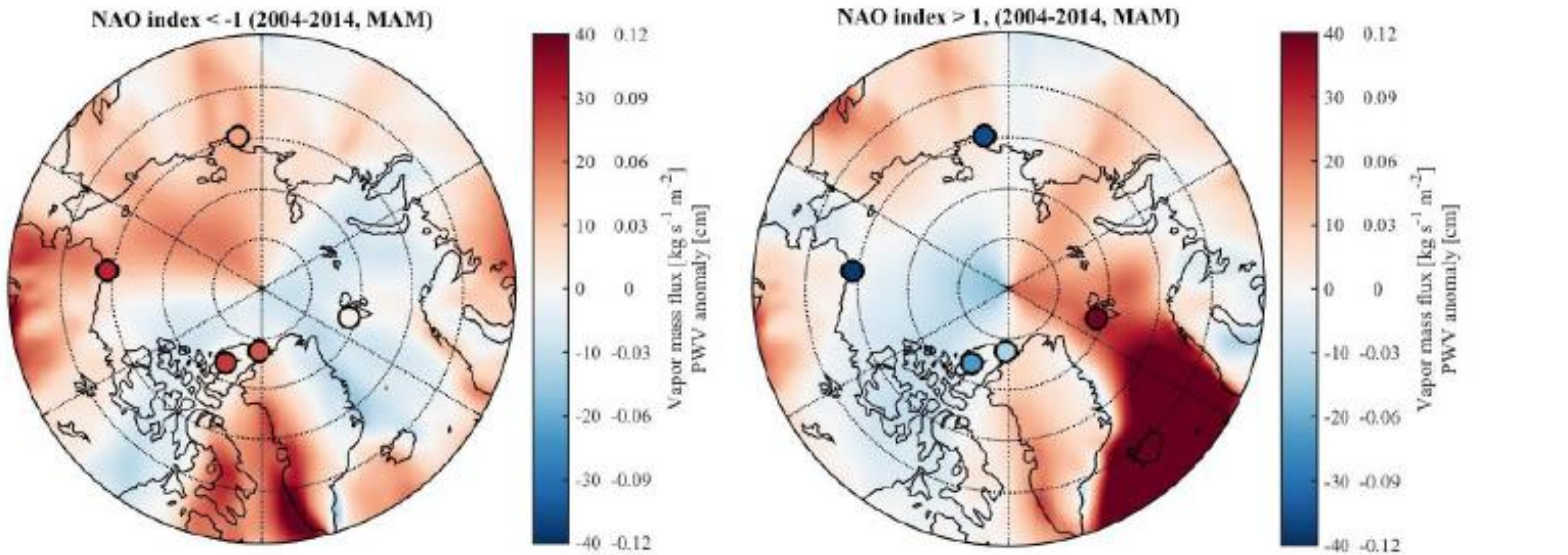
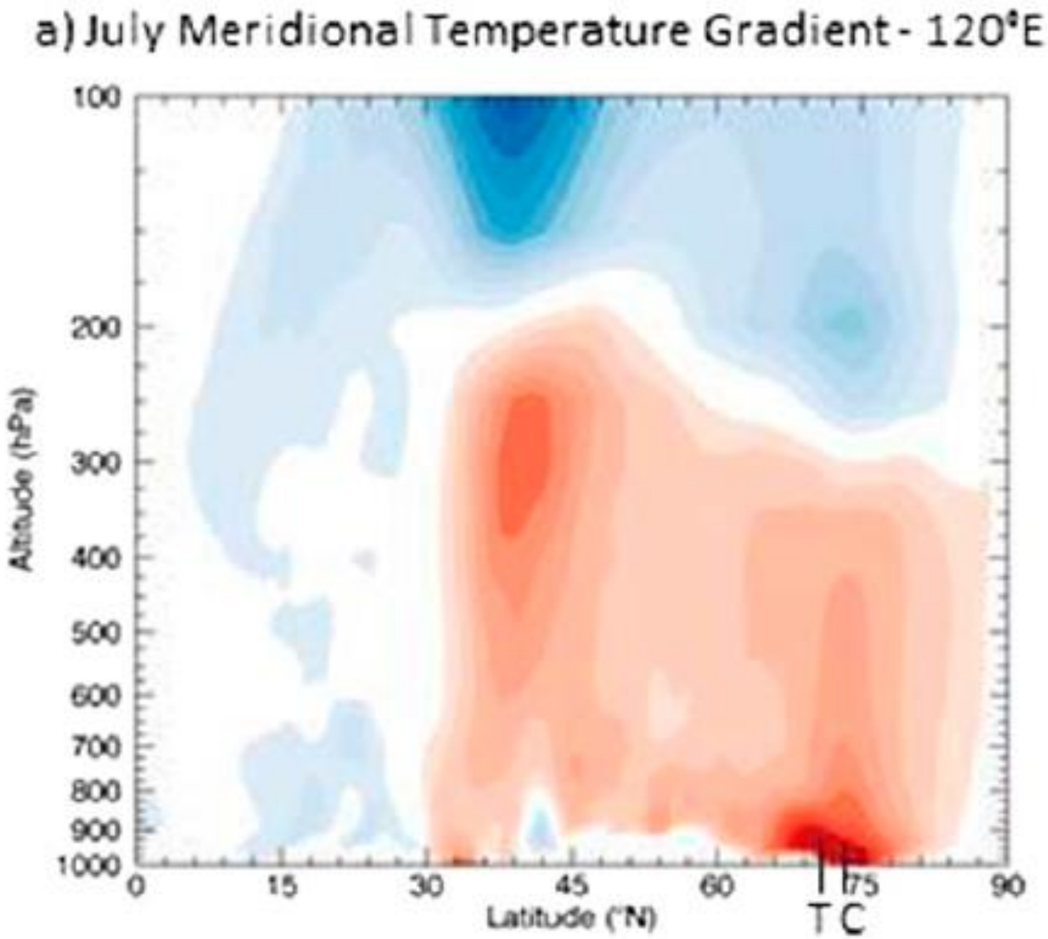


Figure 4. An example of comparison between reanalysis products and IASOA observations for different variables that are linked to each other. The water vapor mass flux based from ERA-Interim (Dee et al., 2011) is plotted for circumpolar high-latitudes and the observed precipitable water vapor anomaly is plotted for the sites of five IASOA observatories. The fields differ between springs (MAM) of strongly negative (left) and positive (right) NAO index.

Interesting opportunity

Meridional air temperature gradient is growing at the Arctic coastal zone in summer, as land is warming much faster than the sea. What will be the effects?



Crawford and Serreze (2015)

Linkages between IASOA and other regional and global initiatives

Global networks each having a specific focus:

Global Atmosphere Watch (GAW)
Baseline Surface Radiation Network (BSRN)
Global Cryosphere Watch (GCW)
Global Climate Observing System (GCOS)
Reference Upper-Air Network (GRUAN)
Total Carbon Column Observing Network (TCCON)
Aerosol Robotic Network (AERONET

Regionally together in the Arctic within IASOA and SAON

- Europe's International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT)
- Pan-Eurasian Experiment (PEEX)
- Integrated Arctic Observing Systems (INTAROS)

Year of Polar Prediction (YOPP)

(a) development of interoperable, error-corrected climatology of long-term meteorological observations and other key data
(b) exploration of impact of Arctic observations on forecast models,
(c) identification of specific regimes for forecast improvements and most sensitive locations,
(d) coordinated experiments for enhanced observations across the IASOA network during YOPP (e.g. four daily radiosonde soundings)

Future perspectives

Present observations serve for numerous valuable studies on regional processes and transports.

- concrete work plan needed

Further advance via more observations:

- filling measurement gaps at individual stations of high-resolution vertical profiles of wind, air temperature and humidity, cloud water and ice content, and aerosols. Possibilities to follow the practices at Barrow, Eureka and Summit at other stations? Cost-effective?
- additional stations to fill geographical gaps. Cape Baranova.
- more spatially distributed measurements around present stations -> information on horizontal variability -> better comparisons against gridded products
- application of recent advances in measurement technology (UAVs etc.)

Consider the priority of actions taking into account the expected advances in (a) satellite remote sensing, (b) other in-situ observations, and (c) numerical models and data assimilation systems.

Better integration with studies on:
Arctic hydrology, glaciology, oceanography, as well as terrestrial and marine ecosystem research